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POLICY PERSPECTIVE

Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest Loss in Indonesia

Sinan A. Abood¹, Janice Ser Huay Lee¹, Zuzana Burivalova¹, John Garcia-Ulloa¹, & Lian Pin Koh^{1,2,3}¹ Department of Environmental Systems Science, ETH Zürich, CHN G 73.2, Universitätstrasse 16, 8092 Zürich, Switzerland² Woodrow Wilson School of Public and International Affairs, Princeton University, Robertson Hall, Princeton, NJ 08544-1013, USA³ Environment Institute, and School of Earth and Environmental Sciences, University of Adelaide, Adelaide, SA 5005, Australia**Keywords**

Deforestation; carbon emissions; industrial concessions; tree plantation; coal mining; *Acacia mangium*; *Elaeis guineensis*.

Correspondence

Janice Ser Huay Lee, Department of Environmental Systems Science, ETH Zürich, CHN G 73.2, Universitätstrasse 16, 8092 Zürich, Switzerland.

E-mail: janice.lee@env.ethz.ch

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Introduction

Southeast Asia's tropical forests harbor exceptional biodiversity, provide important ecosystem services, and support the livelihoods of local communities (Sodhi *et al.* 2006; Naidoo *et al.* 2009; Page *et al.* 2011b; Jenkins *et al.* 2013). Unfortunately, forests in the region are under increasing threat due to rising demands for food, timber, and other natural resources that are driving widespread deforestation and forest degradation (DeFries *et al.* 2010; Gibbs *et al.* 2010; Foley *et al.* 2011; Wilcove *et al.* 2013). A case in point is Indonesia, which accounts for ~44% of Southeast Asia's forest cover but experiences one of the world's highest deforestation rates, second only to Brazil (Hansen *et al.* 2008; Harris *et al.* 2012; Stibig *et al.* 2013). During 2000–2010, Indonesia lost 0.82 Mha of forest per year (Stibig *et al.* 2013), accounting for ~56% of total forest cover loss in Southeast Asia (Stibig *et al.* 2013). As a result, Indonesia also contributes substantially to

Abstract

Indonesia contributes significantly to deforestation in Southeast Asia. However, much uncertainty remains over the relative contributions of various forest-exploiting sectors to forest losses in the country. Here, we compare the magnitudes of forest and carbon loss, and forest and carbon stocks remaining within oil palm plantation, logging, fiber plantation (pulp and paper), and coal mining concessions in Indonesia. Forest loss in all industrial concessions, including logging concessions, relate to the conversion of forest to nonforest land cover. We found that the four industries accounted for ~44.7% (~6.6 Mha) of forest loss in Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas between 2000 and 2010. Fiber plantation and logging concessions accounted for the largest forest loss (~1.9 Mha and ~1.8 Mha, respectively). Although the oil palm industry is often highlighted as a major driver of deforestation, it was ranked third in terms of deforestation (~1 Mha), and second in terms of carbon dioxide emissions (~1,300–2,350 Mt CO₂). Crucially, ~34.6% (~26.8 Mha) of Indonesia's remaining forests is located within industrial concessions, the majority of which is found within logging concessions (~18.8 Mha). Hence, future development plans within Indonesia's industrial sectors weigh heavily on the fate of Southeast Asia's remaining forests and carbon stocks.

land-based global carbon emissions (Harris *et al.* 2012). Although ~41% (~53 Mha) of Indonesia's forest is under some form of protection (Indonesian Ministry of Forestry 2011), a large proportion of its unprotected forests is located within commercial logging, mining, or plantation concessions, the fate of which has significant bearing on Indonesia's biodiversity and carbon stocks (Harris *et al.* 2012; Wich *et al.* 2012; Carlson *et al.* 2013; Gaveau *et al.* 2013).

A combination of decentralization policies and globalized financial markets has spurred enterprise-driven deforestation in Indonesia over the last two decades (Casson 2000; Jepson *et al.* 2001; Rudel *et al.* 2009). In the late 1980s, large tracts of forests were allocated by Suharto's New Order Government to powerful conglomerates for logging or agricultural development (Holmes 2002; Rudel *et al.* 2009). Since the fall of Suharto's regime, a slew of decentralization laws passed in 2001 conferred greater autonomy to district-level authorities for allocating

Table 1 Area of industrial concessions for each region in Indonesia

	Land area (ha)	Area of industrial sectors (ha)					All industries
		Oil palm	Logging	Fiber	Mining	Mixed concessions	
Kalimantan	53,602,272	8,367,206	9,192,299	4,242,584	2,538,180	4,737,105	29,077,375
Sumatra	47,639,870	3,099,060	1,368,171	4,467,859	1,583,892	767,572	11,286,553
Papua	41,505,929	416,636	10,442,780	1,412,020	NA	275,783	12,547,219
Sulawesi	18,738,282	249,154	1,663,584	441,988	NA	24,141	2,378,868
Moluccus	7,884,757	0	1,325,608	44,330	NA	0	1,369,939
Total	169,371,110	12,132,057	23,992,442	10,608,782	4,122,072	5,804,600	56,659,954

industrial concessions over forested lands for logging, oil and gas exploration, mining activities, and plantation expansion (in particular fiber and oil palm plantations) (Casson 2000; Jepson *et al.* 2001; Burgess *et al.* 2012). Recent remote sensing studies have confirmed significant forest losses from the oil palm and fiber industries (Uryu *et al.* 2008; Miettinen *et al.* 2012; Carlson *et al.* 2013), and have detected forest degradation and increased prevalence of fires from logging activities (Siebert *et al.* 2001). While the mining, and oil and gas exploration industries have also contributed to significant environmental damage (Usher 2013), this has been documented to a lesser extent by remote sensing studies. A recent report has also singled out the oil palm industry as being the largest driver of new deforestation in Indonesia (Greenpeace 2013), although the results of this report have been widely debated (Reyes 2013; RSPO 2013). Crucially, there has been no quantitative assessment of the relative contributions of the various forest-exploiting sectors (oil palm, logging, fiber, mining) to recent deforestation in the whole of Indonesia (but see Gaveau *et al.* 2013 for Kalimantan). Such an assessment will provide much needed baseline data for developing evidence-based policy interventions targeted at the relevant industrial sectors.

Here, we examine two policy-relevant research gaps: (i) the relative magnitudes of recent forest loss and carbon emissions within concessions of oil palm plantations, logging, fiber plantations, and coal mining; and (ii) the extents of natural forest and associated carbon stock that remain within these concessions. We specify here that forest loss in all industrial concessions, including logging concessions, relate to the conversion of forest to nonforest land cover classes.

Analyzing land cover change within concessions

We used 250 m spatial resolution land cover classification maps produced by Miettinen *et al.* (2011) to quantify for-

est loss in Indonesia from 2000 to 2010 (Supporting Information). (Forest loss refers to the conversion of mangrove forests, peat swamp forests, lowland forests, lower montane forests, or upper montane forests to nonforest land cover. Within logging concessions, forest loss refers to the conversion of forests, whether already logged or not, to nonforest land cover.) We obtained the best available and most updated geospatial data on industrial oil palm plantations, logging concessions, fiber plantations, and coal mining concessions for Indonesia from Greenpeace, an environmental nongovernmental organization (NGO) (Table 1). Similar concession datasets have also been used in other recent research (e.g., Wich *et al.* 2012; Carlson *et al.* 2013; Gaveau *et al.* 2013; Lee *et al.* 2013). Logging concessions are designated for selective logging; fiber plantations are used for fast growing tree crop species (e.g., *Acacia mangium*) to supply raw material for pulp and paper production; and oil palm plantations consist of the crop *Elaeis guineensis*, for palm oil production. Coal mining datasets were available only for Sumatra and Kalimantan (see Supporting Information for details). Using the available industrial concession datasets, we conducted a land cover change analysis using ERDAS IMAGINE v2011, and quantified the extent of forest loss (mangrove, peat swamp forest, lowland forest, lower montane forest, and upper montane forest) within these industrial concessions from 2000 to 2010 (see Supporting Information for details). We focused our analyses on Sumatra, Kalimantan, Sulawesi, Moluccas, and Papua, islands that contained 97% (~76.9 Mha) of Indonesia's total forest cover in 2010.

We assumed that forest loss within each concession is ultimately the responsibility of the respective industrial sector. For example, any deforestation within an oil palm concession would add to the total deforestation tally of the oil palm sector. We make no attempt to clarify the proximate mechanisms underlying deforestation within concessions (e.g., illegal logging, small-scale encroachment into concessions, fires), as that is beyond the scope of our analysis. Instead, our primary objectives are to

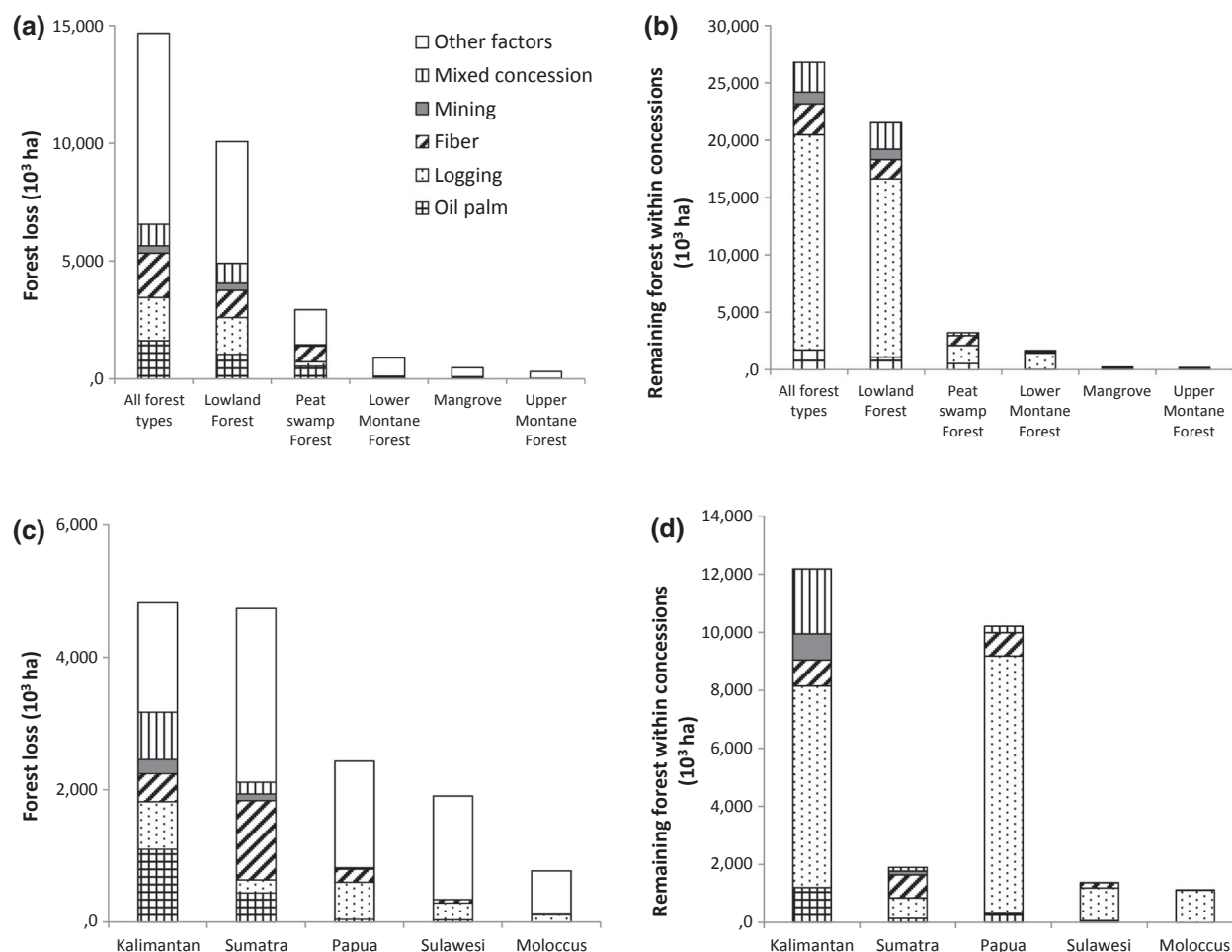


Figure 1 Forest loss in Indonesia from 2000 to 2010 within different industrial sectors, and forest remaining among different industrial sectors based on forest types (a) and (b), respectively, and islands (c) and (d), respectively. Coal mining concessions were unavailable for Papua, Sulawesi, and Moluccas.

determine the relative contribution of each industry to recent forest loss and carbon emissions, and the amount of forest and carbon stock that remains within concessions of each industrial sector. Within logging concessions, we do not take into account carbon emissions from selective logging, as the land cover classification we use does not distinguish between the parts of logging concessions that have already been logged.

Forest loss and carbon emissions

During 2000–2010, Sumatra, Kalimantan, Sulawesi, Moluccas, and Papua lost ~14.7 Mha of forests in total, of which ~44.7% (~6.6 Mha) occurred within industrial concessions, including ~1.9 Mha (~12.8%) in fiber plantation concessions, ~1.8 Mha (~12.5%) in logging concessions, ~1.6 Mha (~11%) in oil palm plantation concessions, ~0.9 Mha (~6.3%) in mixed concessions, and

~0.3 Mha (~2.1%) in mining concessions. Mixed concessions are areas of overlap between concessions (see Supporting Information for details).

Out of the 14.7 Mha of forest lost, ~10.1 Mha was lowland forest. Approximately ~48.7% (~4.9 Mha) of lowland forest loss occurred within industrial concessions, including ~1.6 Mha (~15.5%) in logging concessions, ~1.2 Mha (~11.5%) in fiber plantations, and ~1 Mha (~10.3%) in oil palm plantation concessions. Peat swamp forest loss (~1.4 Mha out of ~2.9 Mha) within industrial concessions occurred mainly within fiber plantation concessions (~665,000 ha; ~22.7%) and oil palm plantation concessions (~534,000 ha; ~18.2%). There were only relatively minor losses of lower montane forest, mangrove forest, and upper montane forest within industrial concessions (Figure 1a).

Among the different islands, the highest forest loss within industrial concessions occurred in Kalimantan

Table 2 Mean estimates for gross carbon dioxide emissions (Mt CO₂) from forest loss within industrial concessions. Values in parentheses represent the percentage of carbon dioxide emissions of each industrial concession, relative to all industrial concessions

	Total emissions	Industrial concessions					All industries
		Fiber	Oil palm	Logging	Mixed concession	Mining	
Kalimantan	3,045–5,824	232–488 (13–14)	749–1,410 (43–39)	311–726 (18–20)	333–745 (19–21)	99–220 (6–6)	1,725–3,588
Sumatra	4,732–8,355	1,257–2,231 (59–57)	523–877 (24–23)	159–327 (7–8)	132–294 (6–8)	66–158 (3–4)	2,137–3,888
Papua	1,846–2,839	120–199 (23–23)	22–38 (4–4)	360–590 (70–69)	15–25 (3–3)	NA	517–851
Sulawesi	993–1,448	24–37 (16–15)	12–21 (7–9)	120–182 (77–75)	0.5–1.1 (0.3–0.5)	NA	156–242
Moluccas	306–635	3–7 (7–8)	0	38–86 (93–92)	0	NA	41–93
Total	10,922–19,100	1,636–2,963 (35.7–34.2)	1,306–2,345 (28.5–27.1)	989–1,911 (21.6–22.1)	481–1,065 (10.5–12.3)	166–378 (3.6–4.4)	4,577–8,662

(~3.2 Mha; ~65.7%), followed by Sumatra (~2.1 Mha; ~44.6%), Papua (~821,000 ha; ~33.8%), Sulawesi (~340,000 ha; ~17.9%), and the Moluccas (~119,000 ha; ~15.3%) (Figure 1c). The largest forest loss in Kalimantan occurred within oil palm plantations (~1.1 Mha out of ~4.8 Mha or ~22.8% of total forest loss in Kalimantan), followed by mixed concessions (~714,000 ha; ~14.8%), and logging concessions (~717,000 ha; ~14.9%). In Sumatra, fiber plantations accounted for the majority of forest loss (~1.2 Mha out of ~4.7 Mha; ~25.3% of total forest loss in Sumatra), followed by oil palm plantation concessions (~440,000 ha; ~9.3%), and logging concessions (~196,000 ha; ~4.1%). Within Papua, Sulawesi, and Moluccas, logging concessions accounted for majority of forest loss among the industrial concessions (Figure 1c).

From 2000 to 2010, gross carbon emissions as a result of forest loss within all industrial concessions for Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas ranged from 4,577 to 8,662 Mt CO₂ or 42–45% of gross carbon emissions from total forest loss (range of values represent carbon dioxide emissions from two scenarios, i) where all lowland forests were logged/disturbed and no peatland burning occurred; ii) all lowland forests were intact and peatland burning occurred; see Supporting Information for more details). Overall carbon emissions were highest within fiber plantation concessions (1,636–2,963 Mt CO₂), followed by oil palm plantation concessions (1,305–2,345 Mt CO₂), logging concessions (989–1,911 Mt CO₂), mixed concessions (481–1,065 Mt CO₂), and mining concessions (166–378 Mt CO₂). In Kalimantan, the oil palm industry contributed to the highest carbon emissions (39–43%), followed by mixed concessions and logging concessions (19–21% and 18–20%, re-

spectively), fiber plantation concessions (13–14%), and mining concessions (6%). In Sumatra, fiber plantation concessions contributed to the highest carbon emissions (57–59%), followed by the oil palm plantation concessions (23–24%), mixed concessions and logging concessions (6–8% and 7–8%, respectively), and mining concessions (3–4%). In Papua, Sulawesi, and Moluccas, logging concessions accounted for the majority of carbon emissions (Table 2).

Remaining forests and carbon stock

Approximately 77.4 Mha of forest remain within Kalimantan, Sumatra, Sulawesi, Moluccas, and Papua, of which ~34.6% (~26.8 Mha) are located within industrial concessions, including ~18.8 Mha (~24.3%) in logging concessions, ~2.7 Mha (~3.5%) in fiber plantation concessions, ~2.6 Mha (~3.4%) in mixed concessions, ~1.7 Mha in oil palm plantation concessions, and ~1 Mha in mining concessions. In terms of forest types, ~21.5 Mha (~46%) of lowland forests, ~3.2 Mha (~33.2%) of peat swamp forests, ~1.7 Mha (~11.9%) of lower montane forests, ~224,000 ha (~18.1%) of mangrove forests, and ~172,000 ha (~3%) of upper montane forests are located within industrial concessions (Figure 1b).

Among the different islands, Kalimantan's concessions contain the largest extent of forests (~12.2 Mha; ~50% of Kalimantan's total forest cover), of which ~10.3 Mha are lowland forests (~61.6% of Kalimantan's lowland forests). In Kalimantan, most remaining forests are found within logging concessions (~7 Mha; ~57.1% of remaining forests in industrial concessions), followed by mixed concessions (~2.2 Mha; ~18.4%), and oil palm

Table 3 Mean estimates of carbon stock (Mt CO₂) in remaining forests within industrial concessions. Values in parentheses represent percentage of carbon stock within each industrial concession, relative to all industrial concessions

	Carbon stock	Industrial concessions					All industries
		Logging	Fiber	Oil palm	Mixed concession	Mining	
Kalimantan	18,598–30,296	3,795–7,435 (55–55)	603–1,157 (9–8)	971–1,699 (14–12)	1,087–2,396 (16–18)	474–940 (7–7)	6,930–13,628
Sumatra	10,982–16,193	714–1,243 (35–36)	937–1,519 (47–44)	165–270 (8–8)	106–222 (5–6)	91–202 (5–6)	2,012–3,456
Papua	20,076–29,596	4,828–7,953 (85–85)	496–823 (9–9)	206–324 (4–3)	172–276 (3–3)	NA	5,701–9,375
Sulawesi	5,422–6,518	722–931 (85–83)	97–139 (12–12)	25–41 (3–4)	2–5 (0.3–0.4)	NA	846–1,116
Moluccas	2,407–4,264	432–903 (98–99)	7–12 (2–1)	0	0	NA	439–915
Total	57,484–86,868	10,491–18,465 (65.9–64.8)	2,141–3,650 (13.4–12.8)	1,367–2,334 (8.6–8.2)	1,366–2,898 (8.6–10.2)	565–1,142 (3.5–4.0)	15,929–28,489

plantation concessions (~1.2 Mha; ~9.9%) (Figure 1d). Papua's concessions contain the second largest extent of remaining forests (~10.2 Mha; ~34.3% of total forests remaining in Papua), most of which are located within logging concessions (~8.9 Mha; ~86.9% of remaining forests in industrial concessions). In Sulawesi and Moluccas, most remaining forests are also found within logging concessions compared to other industries (1.1 Mha and 1.1 Mha, respectively; Figure 1d). Interestingly, in Sumatra, much of the remaining forests is found within fiber plantation concessions (~799,000 ha; ~42% of remaining forests in industrial concessions), followed by logging concessions (~705,000 ha; ~37.1%), and oil palm plantation concessions (~138,000 ha; ~7.3%).

Remaining forests within industrial concessions contain 15,929–28,489 Mt CO₂, or 28–38% of carbon stock from all forests in Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas. Unsurprisingly, logging concessions contain the highest source of carbon stocks (10,491–18,465 Mt CO₂), followed by fiber plantation concessions (2,141–3,650 Mt CO₂), mixed concessions (1,366–2,898 Mt CO₂), oil palm plantation concessions (1,367–2,334 Mt CO₂), and mining concessions (564–1,142 Mt CO₂) (Table 3). In Kalimantan, logging concessions retained the highest carbon stocks (55%), followed by mixed concessions (16–18%), oil palm plantation concessions (12–14%), fiber plantation concessions (8–9%), and mining concessions (7%). In Sumatra, fiber plantation concessions retained the highest carbon stocks (44–47%), followed by logging concessions (35–36%), oil palm plantation concessions (8%), and mining and mixed concessions (5–6%). In Papua, Sulawesi, and Moluccas, logging concessions accounted for the majority of remaining carbon stocks (Table 3).

Regulating deforestation and carbon emissions in Indonesia's industrial sectors

To the extent that our concession dataset is incomplete, we might be underestimating the role of concessions in causing deforestation. Moreover, industrial plantation activities have been shown to occur outside of concession boundaries (Gaveau & Salim 2013). Nevertheless, there are other insidious drivers of forest losses that should not be overlooked, such as small- and medium-scale forest clearing, fires, and illegal logging (Curran *et al.* 2004; Langner *et al.* 2007; Ekadinata *et al.* 2013). Given that ~55.3% of Indonesia's deforestation from 2000 to 2010 occurred outside of industrial concession boundaries, it is important to investigate what other processes could be responsible. Smaller forest opening processes are much more challenging to detect, monitor, and attribute responsibility to than concession development, although recent advances in remote sensing technology are gradually resolving this problem (Asner *et al.* 2009; Margono *et al.* 2012; Rosa *et al.* 2012).

There are important caveats to consider when interpreting our results. First, environmental impacts from the mining industry are likely underestimated since only coal mining for Sumatra and Kalimantan were included. Furthermore, other forms of mining that we did not consider (e.g., gold, copper mining) also threaten Indonesia's forest cover (AFP 2013; Usher 2013). Hence, our reported estimates of forest loss from mining concessions are conservative. Second, we were not able to account for agro-industrial concessions other than oil palm and fiber (e.g., rubber or *Hevea brasiliensis*), which could also be contributing significantly to forest loss in some

parts of Indonesia (Ekadinata & Vincent 2011). Other commodity crops that may play a role in deforestation (e.g., coffee in South Sumatra or cacao in Sulawesi) are also unaccounted for (Clough *et al.* 2009; Gaveau *et al.* 2009), although these are mostly small- or medium-scale land holdings (Koch 2009; Levang *et al.* 2012). Third, we assumed that all forest loss within each concession is ultimately the responsibility of the respective industrial sector. This may not be the case entirely as the date of establishment of the concessions was not taken into account due to incomplete records. For instance, many oil palm and fiber plantation concessions were originally logging concessions. In these cases, the forests might have already been lost due to prior land use (Casson 2000; Kartodihardjo & Supriono 2000). Additionally, present and past small-scale encroachment into concession areas, accidental fire, or illegal logging are just some examples of events that may occur, or could have occurred, within these concessions that may have little to do with the official industrial activities associated with these concessions. Land speculation has also led to "virtual land grabs" in Indonesia whereby leased plantation concessions are used as investment objects or as a front for logging high-value timber but never developed into an oil palm or fiber plantation (Casson 2000; Obidzinski & Chaudhury 2009; McCarthy *et al.* 2012).

We note that the use of different land cover datasets and different industrial concession datasets may give rise to varied figures when it comes to comparing land cover change within Indonesia's industrial sectors. For example, we reported here that 1.2 Mha out of 8.3 Mha (~14%) of oil palm industrial concession in Kalimantan is remaining forests, while Carlson *et al.* (2013) estimated that 8.4 Mha out of 9.3 Mha (~90%) of unplanted oil palm leases was forested. We note that this discrepancy may lie in the following reasons. First, a significant amount of oil palm industrial concessions containing forests may be subsumed under the mixed concession layer due to overlaps with other industrial sectors. Mixed concessions contain a significant amount of forests (~2.2 Mha) in Kalimantan and our study could have under-reported remaining forests in oil palm industrial concessions due to the separation of overlapping oil palm concessions. Second, agroforests mapped under Carlson *et al.* (2013) may have been defined as "plantation/regrowth" under Miettinen *et al.* (2011) land cover dataset. Under our land cover change analysis, the area of "plantation/regrowth" present in oil palm industrial concessions in Kalimantan amounted to around 2.2 Mha (~26%). As we could not differentiate agroforests from plantations within the "plantation/regrowth" land class, we did not consider "plantation/regrowth" as a "forest" land cover class, and may have under-estimated the ex-

tent of agroforests that exist within the oil palm industrial concessions. Lastly, the spatial boundaries for oil palm concessions between Carlson *et al.* (2013) and our study may vary since our data sources were different.

Within Sumatra, fiber plantation concessions accounted for ~590,000 ha of lowland forest loss and ~563,000 ha of peat swamp forest loss (Figure 1). Within Kalimantan, fiber plantations accounted for ~1.6 Mha of lowland forest loss and ~665,000 ha of peat swamp forest loss. The Indonesian Ministry of Forestry has plans to continue investing in the fiber plantation sector, which would entail the possible development of an additional 2 million ha of fiber plantations, particularly within concessions located in Kalimantan and Papua (Obidzinski & Dermawan 2011, 2012). Our analysis suggests that the Indonesian Ministry of Forestry could potentially minimize forest loss by targeting fiber plantation concessions in East Kalimantan which contain large tracts of non-forested land (~9.6 Mha of degraded land) (Obidzinski & Dermawan 2011). While other initiatives have advocated for plantation development to be diverted to nonforested land (Boer *et al.* 2012; Gingold *et al.* 2012), current tax laws on timber revenues create perverse incentives for the issuance of forested land for plantation development, and these laws must be appropriately addressed first (Irawan *et al.* 2013).

Given the significant impacts of the fiber plantation industry on Indonesia's forests, there is an urgent need to better understand the biodiversity value of fiber plantations, including how management practices could be improved for maintaining biodiversity and ecosystem services. At present, biodiversity and ecosystem service research is heavily focused on the oil palm and logging industries, whereas only a few studies exist on the assessment of biodiversity in timber plantations and even fewer on the impact of mining (see Supporting Information for more details).

Fiber plantation and oil palm concessions contributed most substantially to Indonesia's carbon dioxide emissions (Table 2). By overlaying the distribution of peat lands with fiber and oil palm plantation concessions, we found that ~26% of fiber plantation concessions and ~21% of oil palm plantation concessions were located over peat lands (Table S4). More worryingly, ~10% and ~8% of fiber and oil palm concessions, respectively, were located over deep peat (> 3 m in depth). Any development on these lands would contravene Indonesian law (Decree of the President of the Indonesian Republic No.32/1990 concerning Management of Protected Areas or *Keputusan Presiden Republik Indonesia No. 32/1990 tentang Pengelolaan Kawasan Lindung*), which prohibits the deforestation, drainage, and development of deep peat (Wich *et al.* 2011). In particular, the development of fiber

and oil palm plantations over deep peat would result in long-term greenhouse gas emissions, hydrological problems related to the flooding and salinization of freshwater resources, as well as higher risks of peat fires (Wösten *et al.* 2006; Hooijer *et al.* 2010; Page *et al.* 2011a; Hooijer *et al.* 2012). Indeed, recent spatial analysis of the June 2013 haze event showed that 21–47% of NASA's fire alerts were located within fiber and oil palm plantation concessions (Gaveau & Salim 2013; Holmgren 2013; Sizer *et al.* 2013). To protect peat swamp forests within concessions from future development, they could be demarcated as high conservation value forests as part of best management practices of existing sustainability certification initiatives (e.g., Forest Stewardship Council, www.ic.fsc.org; Roundtable of Sustainable Palm Oil, www.rspo.org; Indonesian Sustainable Palm Oil [Paoli *et al.* 2013]). Arrangements might also be made to compensate concession owners for the opportunity costs of withholding development on these lands through payments for ecosystem services, such as the Indonesia–Norway agreement to Reduce Emissions from Deforestation and Forest Degradation (REDD+) (Venter & Koh 2012). REDD+ payments have been shown theoretically to be a feasible option for peat swamp forest conservation as these forests are sufficiently carbon-rich for current carbon prices to compete with the opportunity costs of other industrial land uses (Venter *et al.* 2009; Irawan *et al.* 2013).

Logging concessions retain ~33% of lowland forests (~15.5 Mha) and ~16% of peat swamp forests (~1.6 Mha) in Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas. Gaveau *et al.* (2013) showed that logging concessions maintained forest cover as efficiently as protected areas, provided they were not reclassified for industrial plantation development. A growing number of studies also suggest that selectively logged forests might be valuable for biodiversity conservation (Edwards *et al.* 2011; Gibson *et al.* 2011; Putz *et al.* 2012). Indeed, well-managed logging concessions might present a realistic and cost-effective strategy for forest protection in addition to protected areas (Fisher *et al.* 2011; Gaveau *et al.* 2013).

In our analysis, there were substantial overlaps between different types of industrial concessions, which we considered to be mixed concessions (Figure 1). Verifying the ownership of these mixed concessions would be a crucial task for policy makers, considering that mixed concessions accounted for substantial amounts of forest loss, and remaining forest cover and carbon stocks in some islands (e.g., Kalimantan; Figure 1, Tables 1–1). It is important to have greater transparency and more precise delineation of concession boundaries to improve accountability in cases of environmental damage, such as the widespread fire events on Sumatra in June 2013 that

resulted in transnational haze pollution in Southeast Asia (Sizer *et al.* 2013; Tay & Chua 2013). The Indonesian government is already responding to calls from neighboring countries to do so by developing a “One Map” initiative where a single map layer is to be produced, clarifying land ownership and concession boundaries in Indonesia (Anderson 2013). This map is not just crucial for environmental purposes, it could also help reduce the level of social conflicts with local communities (de Leon *et al.* 2013).

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1: Area of overlap among industrial sectors for each region

Table S2: Carbon content values for above-ground biomass (AGB) and below-ground biomass (BGB) for different land cover classes

Table S3: Results of a simple count of publications that deal with the studied industries and their impact on the environment and development in Indonesia

Table S4: Area of concessions found over peatlands and over deep peat (>3 m) (ha). Values in parentheses represent the percentage of concession area found over peatlands. Figures were calculated by overlaying the concession maps described in section 1.2 and the map of peatlands from Wetlands International (available http://www.wetlands.or.id/publications_maps.php, accessed 03.10.2013)

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